3.4.4 OPERATION AND MAINTENANCE OF PREFILTERS

All materials of construction for prefilters must be compatible with those of the downstream HEPA filters they are designed to protect. Therefore, they must conform to the rigorous physical properties prescribed for HEPA filters, e.g., resistance to shock, vibration, tornado, earthquake, moisture, corrosion, and fire. Survivability under the specific operational conditions and requirements must be addressed when prefilters are selected because moisture or corrosive products in the airstream may limit the choice of filter. Although many filter media will not withstand acid or caustic attack, glass fibers are corrosion-resistant except for fluorides. However, the casing and face screen materials may be less so. Aluminum may deteriorate in marine air, from caustics, or from carbon dioxide. Plastics have poor heat and hot air resistance and generally will not satisfy UL requirements. Condensation from high humidity and sensible water may plug a prefilter and result in more frequent replacement. In general, a prefilter made of construction materials identical to those in the HEPA filter will have equivalent corrosion and moisture resistance. Any increase in resistance from moisture accumulation will be greater for ASHRAE Class III filters than for Class I or II filters. UL classifies ventilation air filters in two categories with respect to fire resistance.[31] When clean, UL Class I filters do not contribute fuel when attacked by flame and emit a negligible quantity of smoke. UL Class II filters are permitted to contain some small amount of combustible material, but they must not contribute significantly to a fire. The collected material on in-service UL-approved Class I and II filters may burn vigorously and create a fire that is difficult to extinguish. Therefore, use of a UL-rated prefilter should not lead to an unwarranted sense of security on the part of the user. UL maintains a current listing of filters that the requirements of their standards.[32]

Most types of prefilters are suitable for continuous operation at temperatures not exceeding 65 to 120 degrees Celsius (149 to 248 degrees Fahrenheit). Other types with glass-fiber media in steel or mineral board frames may be used at temperatures as high as 200 degrees Celsius (392 degrees Fahrenheit). Users of high-temperature prefilters should take a conservative view of performance claims, particularly claims related to efficiency at operating temperature.

Because of waste disposal requirements, the preferred choice of a prefilter for nuclear applications is the single throwaway cartridge. A replaceable-medium filter offers an advantage over the throwaway because the bulk of material that needs to be discarded is smaller and handling and disposal costs are minimized. However, re-entrainment of contaminants and contamination of the peripheral area are possible because the medium is removed from the system and prepared for disposal. The replaceable-medium type is not recommended for toxic exhaust systems. The cleanable-medium filter is undesirable for nuclear systems because of the extensive downtime of the system that is required for changing and decontaminating areas in proximity to the filter installation.

3.5 DEEP-BED FILTERS

Deep-bed filters were designed, built, and placed in service early in the development of nuclear technology for treating off-gasses from chemical processing operations. The first, a sand filter, was constructed at the Hanford, Washington nuclear facility in 1948, and deep-bed glass fiber filters were constructed soon after. These were not considered competitive with then-current versions of the HEPA filter (the CWS-Type 6 or AEC-Type 1), but were thought to have a different function. With the thin-bed filters, the intent is usually to replace or clean the filter medium periodically. The deep-bed filter, on the other hand, usually has as its objective the installation of a unit which will have a long life, in the dust capacity sense, of say five to twenty years, corresponding to either the life of the process or the mechanical life of the system. Thus, when the resistance starts increasing rapidly, the entire filter installation will be abandoned and replaced with a new unit rather than replacing or cleaning the filter medium. In fact, the life span of some of the deep-bed filters constructed during the early 1950s has not yet been entirely expended. A partial explanation for this longevity is the original design concept that deep-bed filters will be used where the total aerosol concentration is usually on the order of or less than normal atmospheric dust concentrations. An important reason for selecting sand for the initial bed material was a need to filter large volumes of wet corrosive aerosols for which more usual filter materials would prove unsatisfactory. Deep beds of crushed coke had been used by the chemical manufacturing industry for many years prior to 1948 to remove sulfuric acid mist from the effluent gas of sulfuric acid manufacturing plants. Silverman cited efficiencies as high as 99.9 percent by weight for a crushed-coke bed against a sulfuric acid mist of 0.5 to 3.0 µm in diameter.[33] Perhaps a carbon-filled bed was considered unsuitable for filtering an aerosol that might contain fissile material, and sand was selected for the first deep-bed filter for nuclear fuel processing facility ventilation air.

3.5.1 DEEP-BED SAND FILTERS

Initially, sand filters were installed at the Hanford, Washington nuclear facility and at the Savannah River nuclear plant. Following their success, more were added at Hanford and Savannah River and others were constructed at plants in Morris, Illinois, and Idaho Falls, Idaho. A bibliography of deep-bed sand (DBS) filters was compiled by Argonne National Laboratory. These DBS filters had collection efficiencies for particles greater than or equal to 0.5 µm that compared favorably with the HEPA filters of that era. Their advantages for the nuclear programs at these sites included large dust-holding capacity, low maintenance, chemical resistance, high heat tolerance, fire resistance, and a capability to withstand large shock and gross pressure changes without operational failures. They also had disadvantages such as high capital costs, need for large areas and volumes, inability to maintain the granular fill, and lack of a reasonable means of disposing of the contaminated fill.

DBS filters contain up to 10 ft of rock, gravel, and sand constructed in graded layers that diminish granule size by a factor of 2 as the layers go from bottom to top. Airflow direction is upward so that granules decrease in size in the direction of flow. A top layer of moderately coarse sand is generally added to prevent fluidization of the finest sand layer underneath. The rock, gravel, and sand layers are positioned and sized to provide the desired structural strength, particle collection ability, dirt-holding capacity, and long service life. Ideally, the layers of the largest granules, through which the gas stream passes first, remove all the large airborne particles, whereas the fine sand layers on top retain the finest smallest particles at high efficiency. Below the granular bed there is a layer of hollow tile that forms passages for air distribution. The total bed is enclosed in a concrete-lined pit. The superficial velocity is about 2.5 cm/sec, and pressure drop across the layers of granules, sized 88 mm to 100 µm, is from 1.5 to 3 kPa. Collection efficiencies as high as 99.98 percent for test aerosols have been reported. Some DBS filters have experienced premature plugging at relatively low dust loadings. Another suffered partial collapse from disintegration of grout between the tiles supporting the overhead filter structure. These failures were caused by moisture leaking through voids in the system perimeter or by chemical corrosion and erosion of system components from nitric acid fumes in the effluent air. Disposal of inoperable DBS filters, usually contaminated, is generally accomplished by sealing and abandonment. Replacement systems normally are constructed nearby to accommodate the same air intake duct system.

Currently, there is renewed interest in sand filters for ESF applications in liquid-metal-cooled fast breeder reactors and for emergency containment venting for light-water reactors. The Swedish containment venting system, known as FILTRA, features large concrete silos filled with crushed rock. It is designed to condense and filter the stream blown from the containment and to release to the atmosphere less than 0.01 percent of the core inventory.

3.5.2 DEEP-BED GLASS FIBER FILTERS

The rapidly emerging glass fiber technology of the late 1940s shifted attention to the use of very deep beds (1 or more m thick) of graded glass fibers as a satisfactory substitute for sand filters when treating gaseous effluents from chemical operations. They proved to be more efficient, less costly, and to have a lower airflow resistance than the DBS filters they replaced. In addition, these deep-bed glass fiber (DBGF) filters employ a medium that has more controllable physical features and more assured availability than the

DBS to permit a larger airflow per unit volume at lower pressure drop, lower operating costs, and potentially lower spent-filter disposal costs. DBGF filters have been used at Hanford for several decades on their Purex process effluent streams. However, the DBGF filters do not have the corrosion resistance of the DBS, particularly from HF, and are less fire-resistant as well. The DBGF is also less of a heat sink and has less capability to resist shocks and high-pressure transients.

The intake segment of the DBGF filter system was designed with layered beds of uniform-diameter glass fibers to a total depth of 24 m. Each layer in the direction of airflow was compressed to a higher density and enclosed in a stainless steel tray with impermeable walls and a perforated screen above and below. Capacity varied from 350 to 350,000 m^3/hr (206 to 206,002 cfm). Although the first unit constructed at Hanford was small (400 m^3/hr (235.4 cfm), many of the 25 subsequent units were much larger and experienced extensive usage from nuclear fuel processing to hot cell ventilation. The glass fiber of preference for this application was Owens-Corning's 115-K, a 29-μm-diameter, curled glass fiber that resisted clumping, settling, and matting. A system that was designed for downward airflow became inoperative from precipitation of ammonium nitrate at the filter face. Subsequent units were designed with air flowing upward and were equipped with water sprays directed from below to dissolve salt precipitation on the intake face to reduce pressure drop buildup. The design airflow velocity of a typical DBGF was 25 cm/sec, and clean pressure drop was close to 0.4 kPa. Final pressure drop, after a total particle loading estimated at 5,000 kg, was 2 kPa. The final stage of a second-generation DBGF filter system employed two 12-mm blankets of 3.2-μm- and 1.2-μm-diameter glass fibers fabricated as a twin-layer bag stretched over a stainless steel framework. Airflow from the first stage passed through the filtration blankets from the outside to the inside, then was exhausted from inside the metal framework. The number of bag filters was proportional to the capacity of the intake segment of the DBGF filter. Later designs of the DBGF filter's cleanup stage substituted HEPA filters in a group of manifolded caissons (encapsulating filter holders), and a comparable increase in collection efficiency was realized. The most recent installation of a DBGF filter system required more than 100 HEPA filters downstream of a deep bed containing more than 15,000 kg of 115-K fiber. By carefully selecting the packing density, bed depth, and airflow velocity, collection efficiencies greater than 99 percent for 0.5 μm particles were attained.

Provision for periodic backflushing will often extend the life of the total filter. Most DBGF filter systems, contained in vaults below ground, are resistant to shock and overpressure from natural phenomena. The dust-holding capacities of DBGF filters are very large, and many units have operated for years without attendance or maintenance. Pressure drop sensors can often predict evolving difficulties and indicate when it is time for backflushing, precipitate dissolution, or other preplanned remedial actions. Just as for DBS filters, decontamination and disposal is difficult for small systems and nearly impossible for the larger systems.

3.5.3 DEEP-BED METAL FILTERS

Deep beds of metal fibers have a number of applications in the nuclear industry, particularly where maximum resistance to fires, explosions, and overpressure shocks are essential. They are also a preferred construction material for filters intended for use in liquid-metal-cooled reactors because of the low resistance of glass to corrosive attack by sodium and its oxides. In offgas systems containing substantial concentrations of HF, use of stainless steel metal fibers has been studied as a substitute for glass.

In most cases, the objective when using metal fiber filters is to obtain particle collection efficiencies that duplicate those obtainable with HEPA filters. However, the unavailability of metal fibers with diameters close to or below 1 μm makes it necessary to provide great filter depth as a substitute for small fiber collection efficiencies. For sodium fire aerosols, high collection efficiency can be obtained with relatively large diameter metal fibers because the combustion products in air, sodium oxide, and carbonate rapidly form large flocs that are easily filtered. The ease of filtration results in the extremely rapid formation of a high-resistance filter cake that severely limits the amount of sodium aerosol particles that can accumulate in the filter before the limit of the fan's suction pressure is reached. Here, the requirement is for a graded-efficiency, deep-bed, metal filter with a large storage capacity in the initial layers of the filter for the fluffy sodium aerosol particles, a high efficiency for small particles in most downstream layers of the filter, and the elimination of abrupt interfaces between graded fiber layers where a filter cake might form. This is a different filtration requirement than obtaining high efficiency for low concentrations of small, nonagglomerating particles—instead, the requirement is for uniform particle storage throughout the depth of the filter. Here also, uniform diameter fibers can be used in great depths, as in the DBGF filters, to substitute for the presence of very small-diameter filter fibers.

Other types of metal filters have been constructed by sintering stainless steel powders or fine fibers into a sieve-like structure that functions very much like a conventional pulse-jet-cleaned industrial cloth filter. The metal membrane has an inherent high efficiency for particles greater than a few micrometers, but depends on the formation of a filter cake to obtain high efficiency with submicrometer particles. Clean airflow resistance is high and increases rapidly as cake thickness builds up. It is cleaned periodically by backflow jets of compressed air. Efficiencies are comparable with those of HEPA filters when the sintered metal filters are precoated with filter aids. Because of their high-temperature resistance and ability to handle high concentrations of mineral dusts, these types of filters have been used in nuclear incinerator off-gas cleaning systems, particularly when heat recovery from the hot filtered gases is desired. However, care must be exercised to avoid releasing tar-like combustion products to sintered filters that are operated at high temperature because the tarry material tends to lodge in the pores and turn to cake that cannot be removed by chemical means or by elevating the temperature to the limit of the metal structure.

Another type of sintered filter construction for high-temperature applications has been prepared from a mixture of stainless steel and quartz fibers. The composite material has the same efficiency and pressure drop as HEPA filter glass paper, but has four times the tensile strength and can operate continuously at temperatures up to 500 degrees Celsius (932 degrees Fahrenheit). Applications of the stainless steel and quartz fiber HEPA filter medium have not proceeded beyond the laboratory stage.

3.6 DEMISTERS

Liquid droplet entrainment separators are required in the standby air treatment systems of many water-cooled and -moderated power reactors to protect the HEPA filters and activated-charcoal adsorbers from excessive water deposition should a major high-temperature water or stream release occur as a result of an incident involving the core cooling system. Droplet entrainment separators are also used in fuel processing operations to control acid mists generated during dissolving operations and subsequent separation steps.

Entrainment separators consisting of a series of bent plates are widely used in HVAC applications for controlling water carryover from cooling coils and humidifiers; but for nuclear applications, their droplet removal efficiency is inadequate. Therefore, fiber-constraining demisters with a much greater efficiency for small droplets are standard for nuclear service. Entrainment separators utilizing fiber media remove droplets by the same mechanisms that are effective for dry fibrous filters, but they must have the additional and important property of permitting the collected water to drain out of the cell before it becomes clogged. Should clogging occur and the pore spaces fill with water, the pressure drop across the separator will rise and some of the water retained in the pore spaces will be ejected from the air discharge side to create sufficient passages for air to pass through. The ejected water can become airborne again by this mechanism.

Droplets from condensing vapors originate as submicrometer-sized aerosols, but the droplets may grow rapidly to multimicrometer size by acting as condensation centers for additional cooling vapors and by coagulation when the concentration of droplets exceeds 106 ml. Droplets produced by firefighting spray nozzles, containment sprays, and other devices that mechanically atomize liquid jets yield droplets that predominantly range from 50 to more than 1,000 μm in diameter. This range of droplet sizes means that entrainment separators must not only be